## RAINFALL DURATION AND INTENSITY IN INDIA.

By ROBERT E. HORTON, Consulting Hydraulic Engineer.

[Voorheesville, N. Y., July 10, 1923.]

The annual rainfall in India ranges from a minimum of less than 4 inches to a maximum of over 450 inches at Cherrapunji. In view of the sharp demarcation between the wet and dry seasons afforded by the monsoon climate generally prevailing, this region affords favorable opportunity for study of the relation between rainfall amount, duration, and intensity. Data of amount of rainfall and rainfall duration in days for over 2,000 stations, having records covering 20 years or more, have been published in the *Memoirs of the Indian Meteorological Department*. The records were grouped according to the amount of rainfall, and the means of the long-term average rainfall and of the average numbers of rainfall days were taken for all stations in a given group and the resulting average number of inches of rain falling per rainfall day were computed. These data are shown in the subjoined table. It is to be noted that in India only days on which one-tenth inch or more precipitation occurred are counted as rainfall days. A total of 2,207 stations was included in the calculation, the group means of rainfall ranging from 6.6 inches per year for stations having less than 10 inches, up to 239.8 inches for stations having over 200 inches per year, the number of rainfall days ranging from 13.3 per year for the group having lowest rainfall, to 140.6 per year for the group having over 200 inches of rainfall. The average amount per rainfall day ranges from 0.5 inch for stations with less than 10 inches to 1.70 inches for stations with over 200 inches per year. There is a consistent progressive increase in the number of rainfall days and amount per rainfall day as the rainfall increases throughout all the records.

The group means of the number of rainfall days were plotted in terms of the mean annual precipitation, as shown by the lines designated (2–a) and (2–b) on Figure 1. Small circles indicate the plotted points. For rainfalls of less than 100 inches per annum the relation is nearly linear and a line designated (3) was drawn showing the relation between the data for this portion of the diagram. The group means of the average amounts per day were also plotted, as indicated by the lines designated (1) and (4) and by triangular symbols. It will be noted that there is a sharp change in the relation between annual rainfal and average amount per day corresponding to a rainfall of 95 inches. For smaller amounts the average rainfall per day is represented by a curve convex upward, while for larger amounts of rainfall per year, the amount per day apparently bears a linear relation to the amount per year. Empirical formulas for the different relation curves were developed as shown on the diagram. The first four formulas are based on the assumptions, first, that up to a rainfall of 100 inches the number of rainfall days is a linear function of the annual rainfall amount; and second, that for rainfalls exceeding 100 inches per year the amount per day is a linear function of the annual rainfall amount. From the fact that the annual rainfall equals the product of the number of rainfall days and the average amount per day, the corresponding formulas for the number of

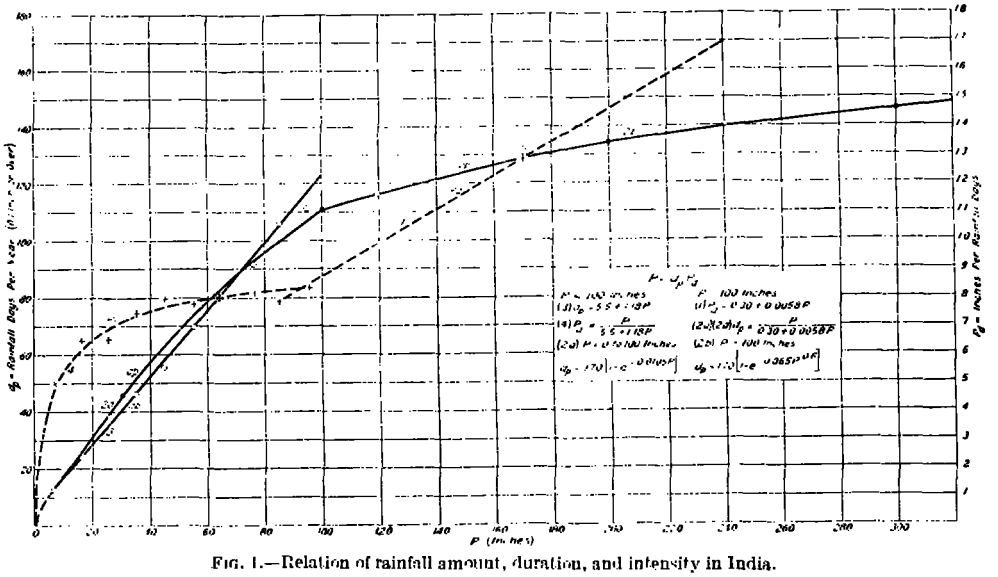

FIG. 1.—Relation of rainfall amount, duration, and intensity in India.

rainfall days in the first instance and amount per day in the second instance were easily deduced.

It appeared at once that none of the four formulas thus far described was wholly rational, as the formulas for rainfall days both indicate that the number of rainfall days per year could be infinite if the amount of precipitation was only large enough. Actually, the number of rainfall days per year can not, of course, exceed 365, and practically owing to the seasonal interchange of the monsoons, the number of rainfall days can not exceed about one-half this number or, say, 180 days per year. The highest number of rainfall days for any single station of record is 161.7, corresponding to a rainfall of 457.8 inches at Cherrapunji. The connected curves (2–a) and (2–b) indicate that the number of rainfall days is a function of the amount of rainfall, probably of exponential form, and approaching a maximum limit of less than 180 as the rainfall increases indefinitely. Accordingly, an attempt was made to represent this curve by an equation of the form,

$$d_p = a[1 - e^{-kp^n}]$$

It was found, however, impossible to fit the entire curve of rainfall days by a single formula. Separate con-

stants are necessary to adapt this equation to the portions of the curve representing numbers of rainfall days per year at stations having over 100 inches, and less than 100 inches rainfall per year, respectively. Two equations of this form, which taken together are in excellent agreement with the plotted points, are shown on the diagram, and the heavy lines (2–a) and (2–b) are plotted from values calculated by these equations. While it seems probable that this type of equation represents a rational form of relation between the number of rainfall days and the amount of rainfall per annum at a given location, there is no reason to expect that the constants in the equation should be uniform over so wide a geographical range of territory as India affords.

Apparently, however, for stations in India having more than 100 inches of rain, a single formula will give approximately accurate results for all stations, and a separate formula will apply equally well to all stations having less than 100 inches of rain. Stations having over 100 inches of rain are mostly at high elevations and their high rainfall is largely due to orographic conditions. Where these conditions exist it may naturally be expected that the relation between the rainfall amount and duration will differ from that pertaining at coastal stations or in flat regions.

As illustrating the probable variation of the number of wet days at a single station from the mean for the same amount of rainfall the data were tablulated for the 61 stations having rainfall amounts between 19 and 21 inches, respectively. For rainfall between 19 and 21 inches, there are 6 cases with the number of days between 22.8 and 25, 24 cases with the number of days between 25 and 30, 25 cases with the number of days between 30 and 35, 2 cases with the number of days between 35 and 40, 4 cases with the number of days between 40 and 45; least number of days, 22.8; greatest number of days, 43; mean number of days, 30.1.

The chance is 4 to 5 that departure for a single station will not exceed one-fifth the mean number. Inspection of the complete data shows similar relations to hold for larger rainfall amounts.

*Summer rainfall rate and duration in India.*

| Amount. | | Number of stations. | Average inches per year. | Average number rain days. | Average inches day. |
|---|---|---|---|---|---|
| From— | To— | | | | |
| 0 | 10 | 91 | 6.6 | 13.3 | 0.50 |
| 10 | 20 | 158 | 15.8 | 24.2 | .65 |
| 20 | 30 | 496 | 25.4 | 38.7 | .66 |
| 30 | 40 | 443 | 34.9 | 46.6 | .75 |
| 40 | 50 | 333 | 44.6 | 55.5 | .80 |
| 50 | 60 | 207 | 54.9 | 70.1 | .78 |
| 60 | 70 | 111 | 64.4 | 80.6 | .80 |
| 70 | 80 | 67 | 75.7 | 92.4 | .82 |
| 80 | 90 | 49 | 84.8 | 106.8 | .79 |
| 90 | 100 | 60 | 94.5 | 111.9 | .84 |
| 100 | 150 | 144 | 118.8 | 116.7 | 1.01 |
| 150 | 200 | 34 | 169.6 | 132.0 | 1.28 |
| 200+ | ..... | 14 | 259.8 | 140.6 | 1.70 |

## ARE WE HAVING LESS SNOWFALL?

By CLARENCE J. ROOT, Meteorologist.

[Weather Bureau Office, Springfield, Ill., Aug. 24, 1923.]

Central Illinois experienced a very light snowfall during the winter of 1922–23; in fact, there have been several successive winters with rather light amounts. This has led numerous persons to make remarks similar to this: "We do not have the big snows that we did when I was a boy, and I do not think we will ever have them again." Is it true that we do not have the big snows that we did, or is it a matter of viewpoint? No doubt the snow that reached to the shoulder of the small boy of the seventies and eighties does not seem very deep to the mature man of 1923. Then, again, many of our city men lived in the country as boys, where the wind has full sweep over the prairies and large drifts are piled up.

Although the snowfall at Springfield has been rather light during several of the more recent winters, the greatest fall of record, 43 inches, occurred as late as the winter of 1913–14. The Springfield winter totals have been averaged for periods of 10 years, beginning in 1884, with the following results: 20.3, 19.6, 21.9, and 20.3 inches. Thus it will be seen that there has been no material change in 40 years. The largest fall in December occurred in 1915, in January in 1918, in February in 1900, and that of March in 1906.

The Illinois climatological reports make mention of heavy snows in recent years. In January, 1912, there was as much as 21 inches in the southern part of the State, with individual falls of 15 inches. On February 22–23, 1914, a severe snowstorm occurred in central Illinois. The wind piled the snow into deep drifts, the snow being 5 to 15 feet deep in places. Business was almost at a standstill and railroad lines were demoralized.

January of 1918 was the severest month in the climatological history of Illinois. The low temperature and heavy snowfall, combined with strong winds, were very unusual. The average snowfall was almost double that of any previous January, and was considerably more than that of any previous month. The greatest total, 42.5 inches, occurred at Chicago, where the most unusual snowfall conditions in the history of the city occurred. The storm of the 6th was the severest since the weather station was established in 1871, but that of the 11th was still more so. The storm of the 11th was of the blizzard type and extended over the entire State, causing the most general and complete transportation paralysis in many years, if not in the history of Illinois railroads. Deep drifts formed, in many cases covering hedges and fences, and many wagon roads were completely blocked even as late as the end of the month. Trains were stalled all over the State. On many sections of main-line railroads there was no train movement for two or three days, and branch lines were blocked for a longer period, 10 days in one case.

During a single week of March, 1923, unusually heavy snow fell over Wisconsin and northern Illinois. At Freeport, Ill., the snow reached an accumulated depth of 25 inches. For Wisconsin the monthly average was the greatest of record for March.

In discussing this subject it may be of interest to know what has happened in other States. The following statement with reference to the winter of 1922–23 was made by Dr. C. F. Brooks in the *Bulletin of the American Meteorological Society:*

There was an extraordinary amount of snowfall in New England during the last winter. December had two times the normal amount. In January the snowfall in northern New England was twice and in the southern portion three times the average. This was followed by the usual amounts in February and March. At Portland the January